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(57) Abstract

A dense wavelength division multiplexer for the separating of an optical signal into optical channels is provided. The dense wavelength division multiplexer of the present invention includes a mechanism of inputting an optical signal where the optical signal contains a plurality of optical channels; a mechanism of separating one or more of the plurality of optical channels by introducing a phase difference between at least two channels of the optical signal; and a mechanism for outputting the separated plurality of channels along a plurality of optical paths. The mechanism of separating one or more of the plurality of optical channels includes utilizing glass blocks and a nonlinear interferometer. The present invention provides an ease in alignment and a higher tolerance to drifts due to the increase in the width of the pass bands. It may also be easily modified to perform the add/drop function as it separates channels. The materials required to manufacture and implement the dense wavelength division multiplexer in accordance with the present invention are readily available. The present invention thus does not require special or expensive or materials or processes. It is thus cost effective.

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FIBER OPTIC DENSE WAVELENGTH DIVISION MULTIPLEXER WITH A PHASE DIFFERENTIAL METHOD OF WAVELENGTH SEPARATION UTILIZING GLASS BLOCKS AND A NONLINEAR INTERFEROMETER

FIELD OF THE INVENTION

The present invention relates to fiber optic networks, and more particularly to fiber optic wavelength division multiplexers.

BACKGROUND OF THE INVENTION

Fiber optic networks are becoming increasingly popular for data transmission due to their high speed and high data capacity capabilities. Multiple wavelengths may be transmitted along the same optic fiber. The totality of multiple combined wavelengths comprises a single transmitted signal. A crucial feature of a fiber optic network is the separation of the optical signal into its component wavelengths, or "channels", typically by a wavelength division multiplexer. This separation must occur in order for the exchange of wavelengths between signals on "loops" within networks to occur. The exchange occurs at connector points, or points where two or more loops intersect for the purpose of exchanging wavelengths.

Add/drop systems exist at the connector points for the management of the channel exchanges. The exchanging of data signals involves the exchanging of matching wavelengths from two different loops within an optical network. In other words, each signal drops a channel to the other loop while simultaneously adding the matching channel from the other loop. The adding and dropping of channels always occur together.

Figure 1 illustrates a simplified optical network 100. A fiber optic network 100 could comprise a main loop 150 which connects primary locations, such as San Francisco and New York. In-between the primary locations is a local loop 110 which connects with loop 150 at connector point 140. Thus, if local loop 110 is Sacramento, wavelengths at San Francisco are multiplexed into an optical signal which will travel from San Francisco, add and drop channels with Sacramento's signal at connector point 140, and the new signal will travel forward to New York. Within loop 110, optical

signals would be transmitted to various locations within its loop, servicing the Sacramento area. Local receivers (not shown) would reside at various points within the local loop 110 to convert the optical signals into the electrical signals in the appropriate protocol format.

The separation of an optical signal into its component channels is typically performed by a dense wavelength division multiplexer. Figure 2 illustrates add/drop systems 200 and 210 with dense wavelength division multiplexers 220 and 230. An optical signal from Loop 110 (λ_1 - λ_n) enters its add/drop system 200 at node A (240). The signal is separated into its component channels by the dense wavelength division multiplexer 220. Each channel is then outputted to its own path 250-1 through 250-n. For example, λ_1 would travel along path 250-1, λ_2 would travel along path 250-2, etc. In the same manner, the signal from Loop 150 (λ_1' - λ_n') enters its add/drop system 210 via node C (270). The signal is separated into its component channels by the wavelength division multiplexer 230. Each channel is then outputted via its own path 280-1 through 280-n. For example, λ_1' would travel along path 280-1, λ_2' would travel along path 280-2, etc.

In the performance of an add/drop function, for example, λ_1 is transferred from path 250-1 to path 280-1. It is combined with the others of Loop 150's channels into a single new optical signal by the dense wavelength division multiplexer 230. The new signal is then returned to Loop 150 via node D (290). At the same time, λ_1' is transferred to path 250-1 from 280-1. It is combined with the others of Loop 110's channels into a single optical signal by the dense wavelength division multiplexer 220. This new signal is then returned to Loop 110 via node B (260). In this manner, from Loop 110's frame of reference, channel λ_1 of its own signal is dropped to Loop 150 while channel λ_1' of the signal from Loop 150 is added to form part of its new signal. The opposite is true from Loop 150's frame of reference. This is the add/drop function.

Conventional methods used by wavelength division multiplexers in separating an optical signal into its component channels includes the use of filters and fiber gratings as separators. A "separator," as the term is used in this specification, is an integrated collection of optical components functioning as a unit which separates one or more channels from an optical signal. Filters allow a target channel to pass through while

redirecting all other channels. Fiber gratings target a channel to be reflected while all other channels pass through. Both filters and fiber gratings are well known in the art and will not be discussed in further detail here.

A problem with the conventional separators is the precision required of a device for transmitting a signal into an optic fiber. A signal entering a wavelength division multiplexer must conform to a set of very narrow pass bands. Figure 3 shows a sample spectrum curve 310 composed of numerous channels as it enters a dense wavelength division multiplexer. The pass bands 320 of the channels are very narrow. Ideally, the curve would be a square wave. A narrow pass band is problematic because, due to the physical limitations and temperature sensitivity of signal source devices, they never emit light exactly at the center wavelengths of the pass bands of an optical filter. The difference between the actual wavelength and the center of the pass band is called the "offset." The amount of offset or change in offset ("drift") ideally should not be larger than the width of the pass band. Otherwise, crosstalk between channels will be too large. Crosstalk occurs when one channel or part of a channel appears as noise on another channel adjacent to it. Since the signals resulting from the conventional wavelength division multiplexer configurations have narrow pass bands, the signal source devices ("transmitters"), such as lasers or the like, must be of a high precision so that drift is limited to the width of the pass bands. This high precision is difficult to accomplish. Signal source devices of high precision are available but are very expensive. Also, the signal source devices must be aligned individually for each separator, which is time intensive.

Therefore, there exists a need for a wavelength division multiplexer with a method of separation which has a greater tolerance for drift and is easier to align. This method should also be cost effective to implement. The present invention addresses such a need.

SUMMARY OF THE INVENTION

A dense wavelength division multiplexer for the separating of an optical signal into optical channels is provided. The dense wavelength division multiplexer of the present invention includes a mechanism of inputting an optical signal where the optical

signal contains a plurality of optical channels; a mechanism of separating one or more of the plurality of optical channels by introducing a phase difference between at least two the channels of the optical signal; and a mechanism for outputting the separated plurality of channels along a plurality of optical paths. The mechanism of separating one or more of the plurality of optical channels includes utilizing glass blocks and a nonlinear interferometer. The present invention provides an ease in alignment and a higher tolerance to drifts due to the increase in the width of the pass bands. It may also be easily modified to perform the add/drop function as it separates channels. The materials required to manufacture and implement the dense wavelength division multiplexer in accordance with the present invention are readily available. The present invention thus does not require special or expensive materials or processes. It is thus cost effective.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 is an illustration of a simplified optical network.

Figure 2 is an illustration of an add/drop system and dense wavelength division multiplexers.

Figure 3 is a graph of two sample spectrum curves, each comprised of several channels as they enter, respectively, a conventional dense wavelength division multiplexer and a dense wavelength division multiplexer in accordance with the present invention.

Figure 4 is an illustration of a preferred embodiment of a separator in accordance with the present invention.

Figure 5 is an illustration of a nonlinear interferometer used with a separator in accordance with the present invention.

Figures 6 and 7 illustrate the odd and even channels of an input signal as they travel through the separator in accordance with the present invention.

Figure 8 is a simple block diagram of a wavelength division multiplexer with a multi-stage parallel cascade configuration of separators in accordance with the present invention.

Figure 9 is a simple block diagram of a separator in accordance with the present invention functioning as a 2 x 2 switch.

Figure 10 is an illustration of a separator in accordance with the present invention performing the add/drop function.

DETAILED DESCRIPTION

The present invention relates to an improvement in a dense wavelength division multiplexer. The following description is presented to enable one of ordinary skill in the art to make and use the invention and is provided in the context of a patent application and its requirements. Various modifications to the preferred embodiment will be readily apparent to those skilled in the art and the generic principles herein may be applied to other embodiments. Thus, the present invention is not intended to be limited to the embodiment shown but is to be accorded the widest scope consistent with the principles and features described herein.

A dense wavelength division multiplexer in accordance with the present invention provides for a higher tolerance to drifts and ease of alignment. Its separators may be placed in a multi-stage parallel cascade configuration to reduce insertion loss. The present invention may also be easily modified to perform the add/drop function as it separates channels. The method does not require special or expensive materials or processes, and thus is cost effective to implement.

To more particularly describe the features of the present invention, please refer to Figures 4 through 10 in conjunction with the discussion below.

Figure 4 illustrates the preferred embodiment of a separator in accordance with the present invention. The separator 400 comprises an input fiber 430 for inputting an optical signal, and two output fibers 440 and 460. It comprises two lenses 470 and 480 which collimate the input signal as it comes from the input fiber 430 and converge the output signal to the output fibers 440 and 460. It also comprises two blocks of glass 410A-410B placed next to each other. Adjacent to one side of the blocks 410A and 410B is a nonlinear interferometer 450 which introduces a phase difference into the even channels while maintaining the same phase for the odd channels. At the place where the two blocks 410A-410B meet, the glass is coated with a reflective coating 420 with a reflectivity, for example, of 50%.

The reflective coating 420 splits the optical signal containing λ_1 - λ_n into at least

two portions 462, 464. In the preferred embodiment, the reflective coating 420 is polarization insensitive. The nonlinear interferometer 450 then introduces a π phase difference into the even channels while maintaining the phase of the odd channels. The two output fibers 440 and 460 are then aligned, or placed at a particular distance from the separator 400, such that even channels are captured in one fiber while the odd channels are captured in the other.

Although the separator in accordance with the present invention has been described with two glass pieces adjacent to a nonlinear interferometer, one of ordinary skill in the art will understand that other materials and configurations may be used to accomplish the same separation of channels without departing from the spirit and scope of the present invention.

An example of a nonlinear interferometer which may be used with the separator 400 of the present invention has been disclosed in co-pending U.S. patent application entitled "Nonlinear Interferometer for Fiber Optic Dense Wavelength Division Multiplexers Utilizing a Phase Differential Method of Wavelength Separation," Serial No. (JAS978P), filed on ______. Applicant hereby incorporates the co-pending application by reference. Figure 5 illustrates a nonlinear interferometer 450 as disclosed in U.S. Patent Application Serial No. (JAS978P). Its structure comprises two glass plates 580A-580B, creating a space 510 therebetween. The inside face of the glass plate 580B is coated with a reflective coating 520 with a reflectivity of 100%. The inside face of the glass plate 580A is coated with a reflective coating 540 with a reflectivity of approximately 18%. A phase bias element 530, preferably of 180 degrees, is placed placed between the glass plates 580A and 580B, protruding partially into the space 510. The 180 degree phase bias element 530 will introduce a phase shift of π into the even channels of the signal 464 while maintaining the phase of the odd channels. The phase bias element 550, preferably of 90 degrees, and the wavelength tuning element 560 change the shape of the curve of the channels, as will be described later.

Figure 6 illustrates the odd channels of an input signal as it travels through the separator 400 of the present invention. An input signal (λ_1 - λ_n) enters the separator 400 through input fiber 430. The signal travels through the lens 470 which contains the signal and directs it toward the glass blocks 410A and 410B. The signal travels through

the glass blocks 410A and 410B, and when it reaches the 50% reflective coating 420, it is split into two signals 462 (-E1) and 464 (E2). Signal 462 travels to and back from the interferometer 450 without a change in its phase. Signal 464 also travels to and back from the interferometer 450, including the 180 degree phase bias element 530, but no phase change is introduced into its odd channels. Thus, when the odd channels of signals 462 and 464 travel back from the interferometer 450, they are in phase. The signals 462 and 464 travel through the glass blocks 410A and 410B again. When they reach the 50% reflective coating 420 again, they travel to the same location, output fiber 440, which is placed in a position such that the phase of the odd channels are captured.

Figure 7 illustrates the even channels of an input signal as they travel through the separator 400 of the present invention. The even channels travel through the separator 400 in same manner as the odd channels, described above with Figure 6, however, when the even channels of signal 464 enter the interferometer 450, they travel through the 180 degree phase bias element 530 which introduces a π phase change. When the signals 462 and 464 travel back from the interferometer 450, their even channels are out of phase. When they reach the 50% reflective coating 420 again, the even channels with the phase change travel to output fiber 460, which is positioned such that the phase of the even channels is captured.

Although the separator 400 of the present invention has been disclosed with an interferometer structure illustrated in Figure 5, one of ordinary skill in the art will understand that other structures which introduce a phase difference between channels of an optical signal can be used without departing from the spirit and scope of the present invention.

By separating channels in this manner, the separator 400 of the present invention broadens the pass and isolation bands of the signals. Referring back to Figure 5, when signals 462 and 464 enter the interferometer 450, they pass through the 18% reflective coating 540. Eighteen percent (18%) of the signals 462 and 464 are reflected by the 18% reflective coating 540 while the remaining 82% travels to the 100% reflective coating 520. The 100% reflective coating 520 sends the remaining signals back across to the 18% reflective coating 540. 18% of the remaining signals are then reflected by the 18% reflective coating 540 while the rest exit the interferometer 450. This 18% that are

reflected then re-travel to the 100% reflective coating 520. This process repeats until substantially all portions of the signals 462 and 464 exit the interferometer 450. By forcing signals 462 and 464 to travel multiple times back and forth through the interferometer 450 before exiting, the controlled changing of the shape of the signals nonlinearly occurs such that the tips of the signal's curves are flattened and a small amount of band shape distortion is allowed. The 90 degree bias element 550 and the wavelength tuning element 560 (Figure 5) fine tune the shapes and positions of the pass bands to their desired properties.

To illustrate the advantage of flattening the curve tips and allowing a small amount of band shape distortion, please refer back to Figure 3. Figure 3 is a graph of spectrum curve 310 of a signal which would result if the reflective coating 540 has a reflectivity of 0%. This curve 310 has no crosstalk but has a very narrow isolation band 330 and a narrow pass band 320. The spectrum curve 340 is a signal which would result if the reflective coating 540 has a reflective index of approximately 18%. There is a small amount of band shape distortion 350, but because of the existence of the band shape distortion 350, the isolation band 360 is significantly wider. In addition, the tips of the curve are flatter, resulting in a wider pass band 370. The amount of flattening and shape change allowed can be manipulated by selecting a reflective coating with a certain reflectivity. Thus, the separator 400 of the present invention, through manipulation of its interferometer 450, can be used to broaden the pass and isolation bands, which makes the curve more stable and tolerant to drift.

Another advantage of the separators 400 of the present invention is the ability to place them in a multi-stage parallel cascade configuration to reduce insertion loss. This configuration is illustrated in Figure 8 and has been disclosed in co-pending U.S. Patent Application entitled "Fiber Optic Dense Wavelength Division Multiplexer Utilizing A Multi-Stage Parallel Cascade Method Of Wavelength Separation," Serial No. 09/130,386, filed on August 6, 1998. Applicant hereby incorporates the application by reference. In Figure 8, an optical signal containing channels λ_1 - λ_n enters the dense wavelength division multiplexer of the present invention 800 through node A (240). The signal passes through a separator of the present invention 810A. The separator 810A divides the signal into two separate signals, one containing the odd channels (λ_1, λ_3, λ_5, ...) (830) and the other

containing the even channels (λ_2, λ_4, λ_6, ...) (840), as described above with Figures 4 through 7. These odd and even channels are each passed through another separator 810B-810C which further divides them by every other channel. This division continues until only one channel is outputted to each optic fiber, 250-1 through 250-n.

Although the separator of the present invention has been described as being utilized with the multistage parallel configuration of the present invention, one of ordinary skill in the art will understand that the separator of the present invention may be utilized with other configurations without departing from the spirit and scope of the present invention.

Another added functionality of a separator 400 of the present invention is the ability to perform the add/drop function while also separating the channels. Figure 9 is a simple block diagram of a separator 900 functioning as a 2x2 switch. As illustrated, two signals containing λ_1 - λ_n and λ_1' - λ_n' are input into the separator 900. Device 900 then could drop the even channels of the first signal to the second signal while adding the even channels of the second signal to the first signal.

To more particularly describe the utilization of a separator to perform the add/drop function, refer to Figure 10 and the discussion below. Figure 10 illustrates a separator in accordance with the present invention performing the add/drop function. The separator 900 in Figure 10 is identical to the separator 400 in Figure 4 except for the input of a second signal containing λ_1' - λ_n' via an additional optical fiber 1040. This second signal would be separated into its odd and even channels similarly to the first signal containing λ_1 - λ_n except the output pathways of odd and even channels are the mirror images of odd and even channels, respectively, from fiber 430. The result is that output fiber 440 would contain the odd channels from the first signal (λ_1, λ_3, λ_5...) plus the even channels from the second signal (λ_2', λ_4', λ_6'...), and output fiber 460 would contain the even channels from the first signal (λ_2, λ_4, λ_6...) plus the odd channels from the second signal (λ_1', λ_3', λ_5'...). By manipulating which separators in a wavelength division multiplexer performs the add/drop function, certain channels can be targeted.

A dense wavelength division multiplexer with a phase differential method of wavelength separation utilizing separators with glass blocks and a nonlinear interferometer has been disclosed. The separators provide an ease in alignment and a

higher tolerance to drifts due to the increase in the widths of the pass bands. They may also be placed in a multi-stage parallel cascade configuration to provide for a lower insertion loss by requiring an optical signal to travel through fewer optical components. The present invention may also be easily modified to perform the add/drop function as it separates channels. The materials required to manufacture and implement the dense wavelength division multiplexer in accordance with the present invention are readily available and do not require special or expensive materials or processes. It is thus cost effective.

Although the present invention has been described in accordance with the embodiments shown, one of ordinary skill in the art will readily recognize that there could be variations to the embodiments and those variations would be within the spirit and scope of the present invention. Accordingly, many modifications may be made by one of ordinary skill in the art without departing from the spirit and scope of the appended claims.

CLAIMS

What is claimed is:

1. A dense wavelength division multiplexer for separating an optical signal into optical channels comprising:

means for inputting an optical signal, the optical signal comprising a plurality of optical channels;

means for separating one or more of the plurality of optical channels by introducing a phase difference between at least two of the plurality of optical channels, wherein the separating means comprises a plurality of glass blocks; and

means for outputting the separated plurality of optical channels along a plurality of optical paths.

2. The dense wavelength division multiplexer of claim 1, wherein the inputting means comprises:

(a) at least one lens optically coupled to the separating means; and

(b) at least one optical fiber optically coupled to the lens.

3. The dense wavelength division multiplexer of claim 1, wherein the outputting means comprises:

(a) at least one lens optically coupled to the separating means; and

(b) at least one optical fiber optically coupled to the lens.

4. The dense wavelength division multiplexer of claim 1, wherein the separating means comprises:

(a) a first and a second glass block, each glass block comprising a first and second face,

wherein the first and second faces reside opposite of each other,

wherein the second face of the first glass block is coupled to the first face of the second glass block,

wherein the first face of the first glass block is optically coupled to the inputting means;

(b) at least one reflective coating residing on the second face of the first glass block and on a corresponding location on the first face of the second glass block; and

(c) a nonlinear interferometer structure optically coupled to the first and second glass blocks.

5. The dense wavelength division multiplexer of claim 4, wherein the reflective coating (b) comprises a reflective coating with reflectivity of 50%.

6. The dense wavelength division multiplexer of claim 4, wherein the nonlinear interferometer (c) comprises:

(c1) a first glass plate optically coupled to a second glass plate, forming a space therebetween;

(c2) a first reflective coating residing inside the space and on the second glass plate;

(c3) a phase bias element residing inside the space; and

(c4) a second reflective coating residing inside the space and on the first glass plate.

7. The dense wavelength division multiplexer of claim 6, wherein the first reflective coating (c2) comprises a reflective coating with a reflectivity of 100%.

8. The dense wavelength division multiplexer of claim 6, wherein the phase bias element (c3) is a 180 degree phase bias element.

9. The dense wavelength division multiplexer of claim 6, wherein the second reflective coating (c4) comprises a reflective coating with a reflectivity of approximately 18%.

10. A dense wavelength division multiplexer for separating an optical signal

into optical channels comprising:

(a) at least one of a first optical fiber for inputting an optical signal, wherein the optical signal comprises a plurality of optical channels;

(b) at least one of a first lens optically coupled to the first optical fiber;

(c) a first and a second glass block, each glass block comprising a first and second face,

wherein the first and second faces reside opposite of each other,

wherein the second face of the first glass block is coupled to the first face of the second glass block,

wherein the first and second glass blocks are optically coupled to the first lens;

(d) at least one reflective coating residing on the second face of the first glass block and on a corresponding location on the first face of the second glass block;

(e) a nonlinear interferometer structure optically coupled to the first and second glass blocks, wherein the interferometer introduces a phase difference between at least two of the plurality of optical channels;

(f) at least one of a second optical fiber for outputting one or more of the plurality of optical channels; and

(g) at least one of a second lens optically coupled to the second optical fiber.

11. The dense wavelength division multiplexer of claim 10, wherein the reflective coating (d) comprises a reflective coating with a reflectivity of 50%.

12. The dense wavelength division multiplexer of claim 10, wherein thc nonlinear interferometer (e) comprises:

(e1) a first glass plate optically coupled to a second glass plate, forming a space therebetween;

(e2) a first reflective coating residing inside the space and on the second glass plate;

(e3) a phase bias element residing inside the space; and

(e4) a second reflective coating residing inside the space and on a portion of the first glass plate.

13. The dense wavelength division multiplexer of claim 12, wherein the first reflective coating (e2) comprises a reflective coating with a reflectivity of 100%.

14. The dense wavelength division multiplexer of claim 12, wherein the phase bias element (e3) is a 180 degree phase bias element.

15. The dense wavelength division multiplexer of claim 12, wherein the second reflective coating (e4) comprises a reflective coating with a reflectivity of approximately 18%.

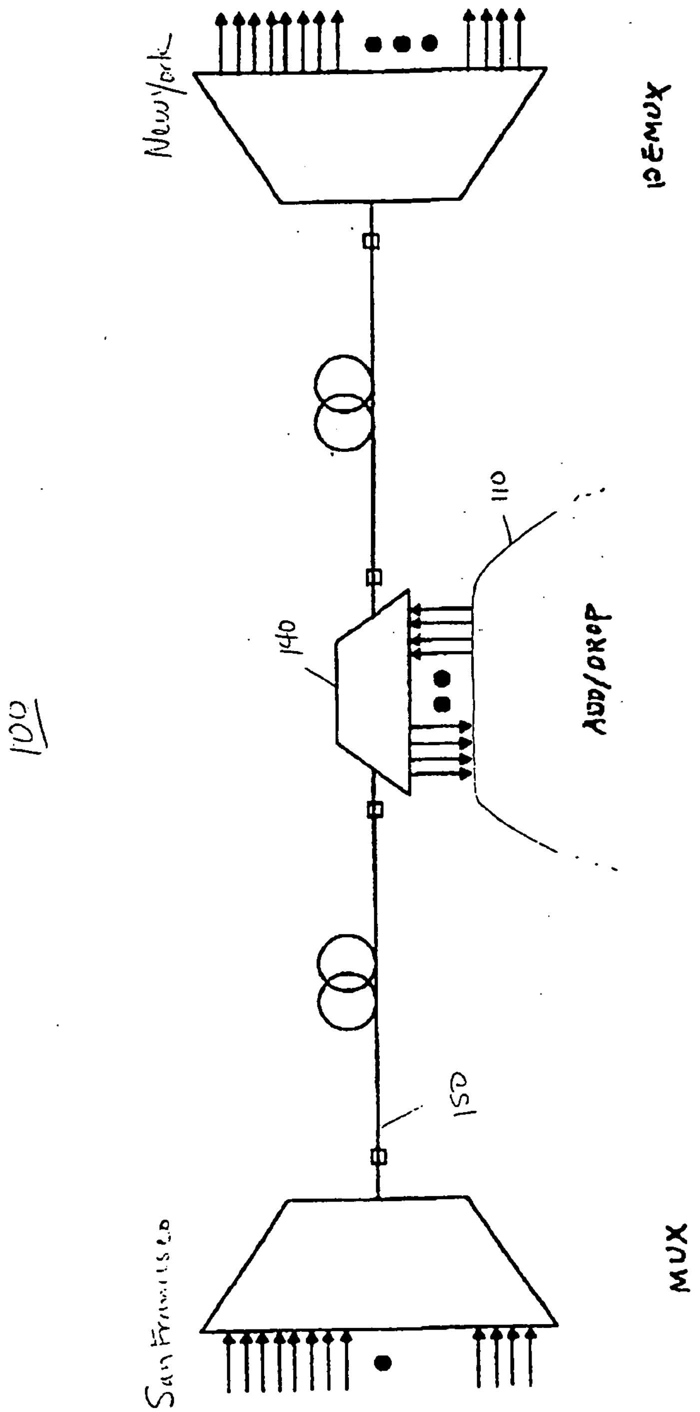

FIGURE 1

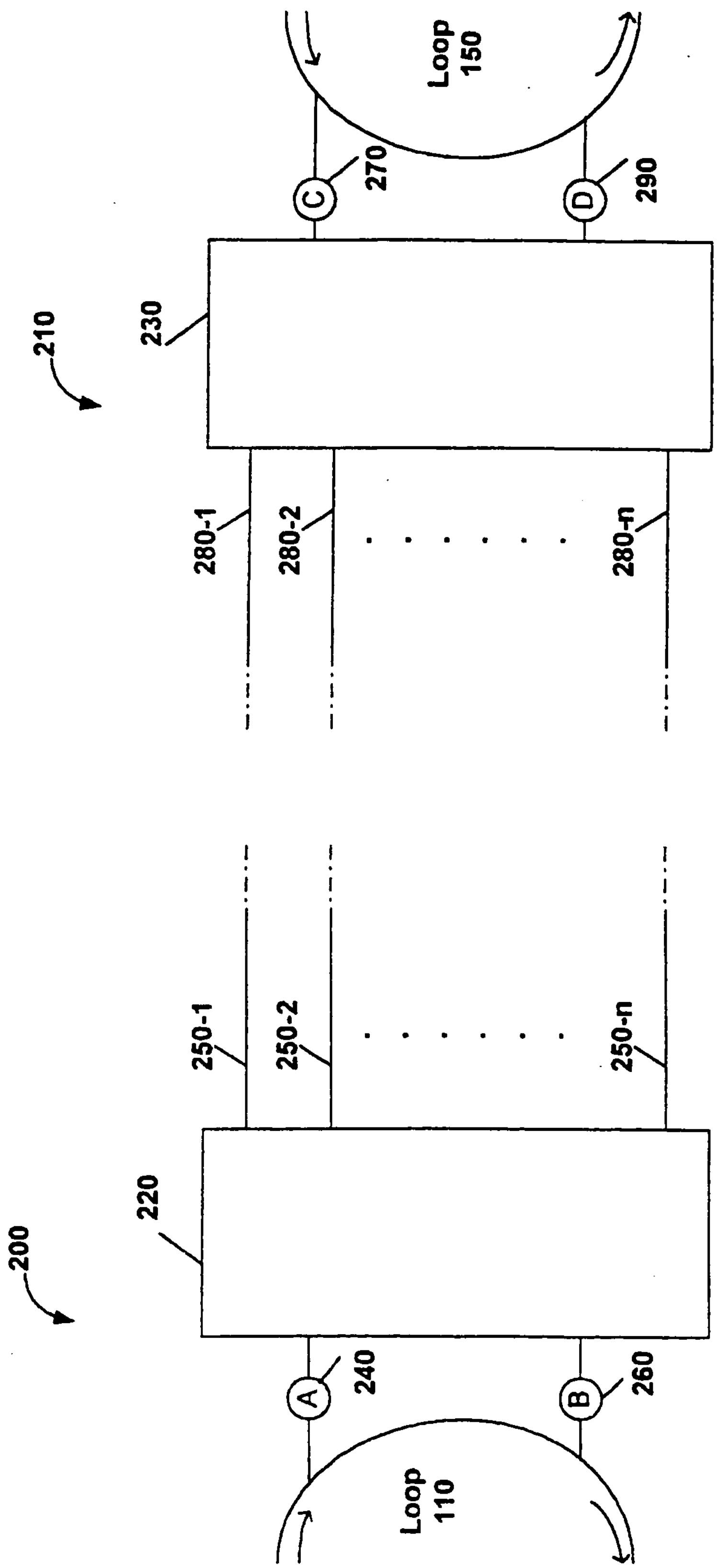
Loop 150
C
270
D
290
230
210
280-1
280-2
280-n
250-1
250-2
250-n
220
200
A
240
B
260
Loop 110

FIGURE 2

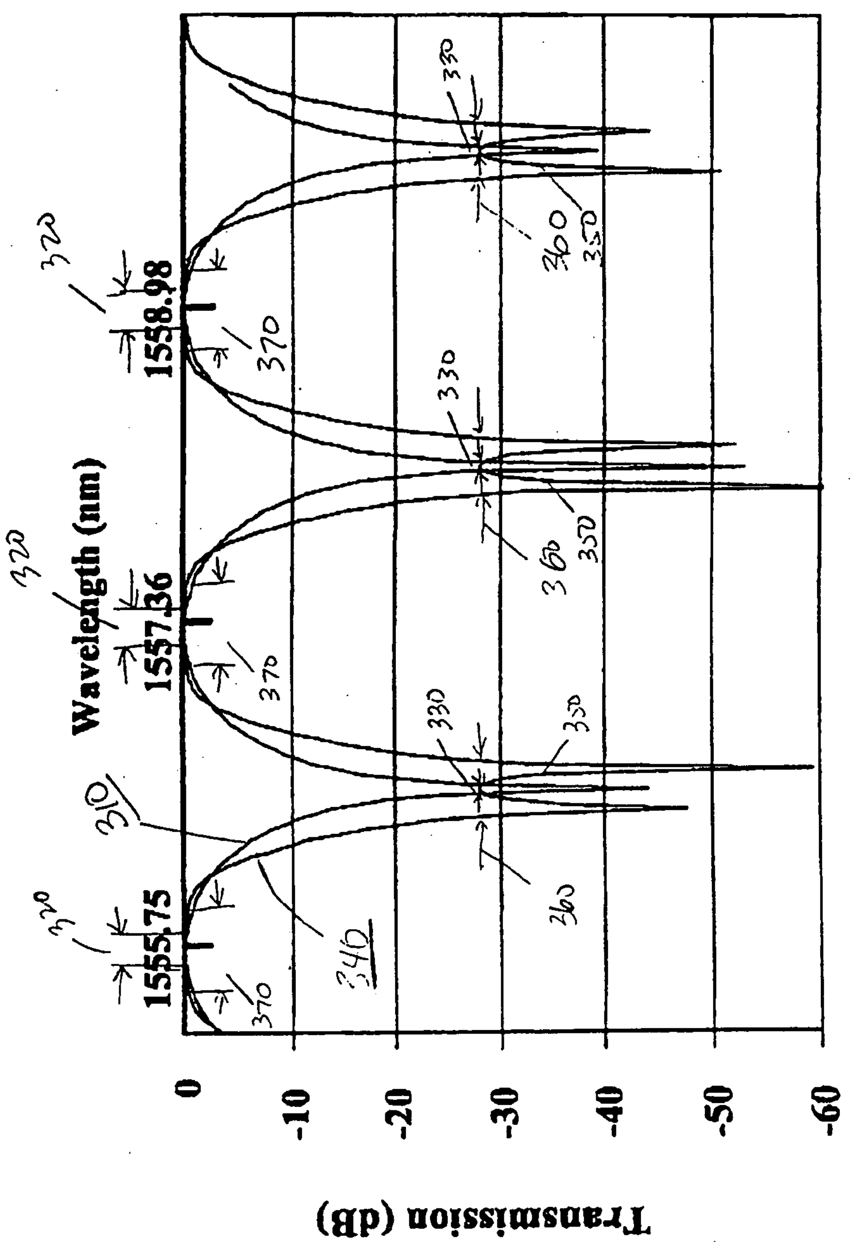
Wavelength (nm)
1555.75
1557.36
1558.98
Transmission (dB)
0
-10
-20
-30
-40
-50
-60
310
320
330
340
350
360
370

FIGURE 3

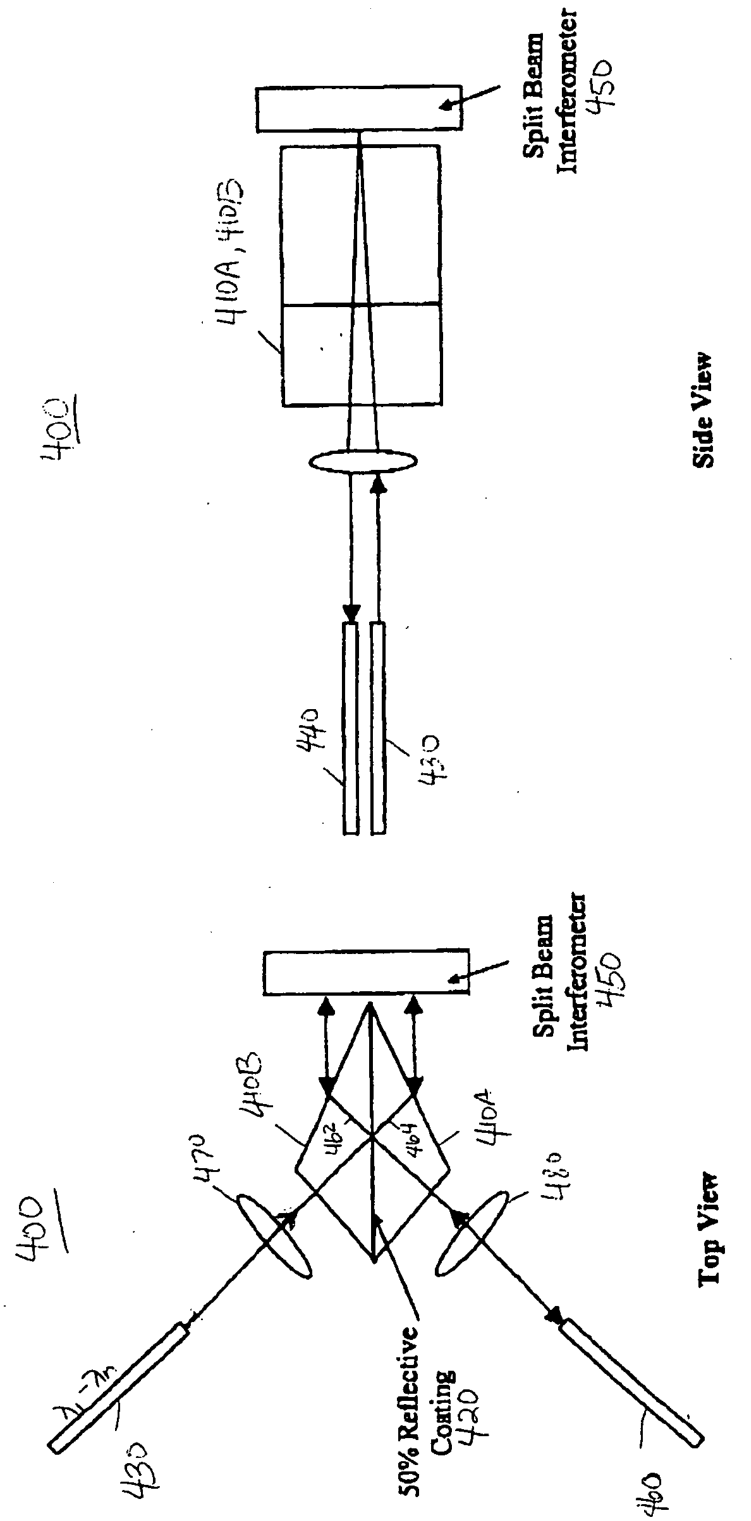
400
Split Beam Interferometer 450
410A, 410B
440
430
Side View
400
Split Beam Interferometer 450
410B
462
464
410A
470
480
λ1-λn
430
50% Reflective Coating 420
460
Top View

FIGURE 4

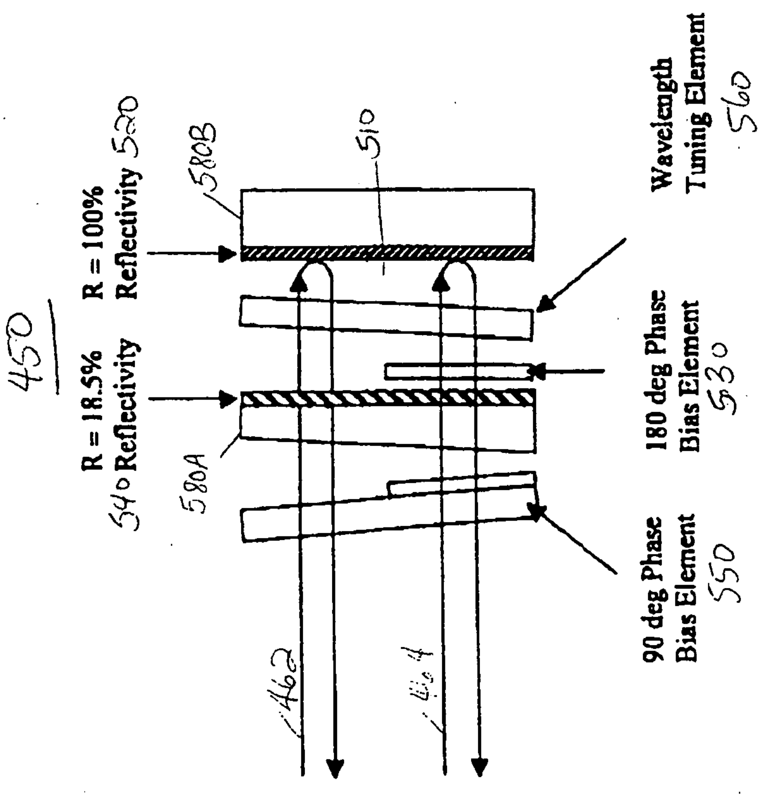
450
R = 18.5% Reflectivity 540
R = 100% Reflectivity 520
580B
510
580A
Wavelength Tuning Element 560
180 deg Phase Bias Element 530
90 deg Phase Bias Element 550
462
464

FIGURE 5

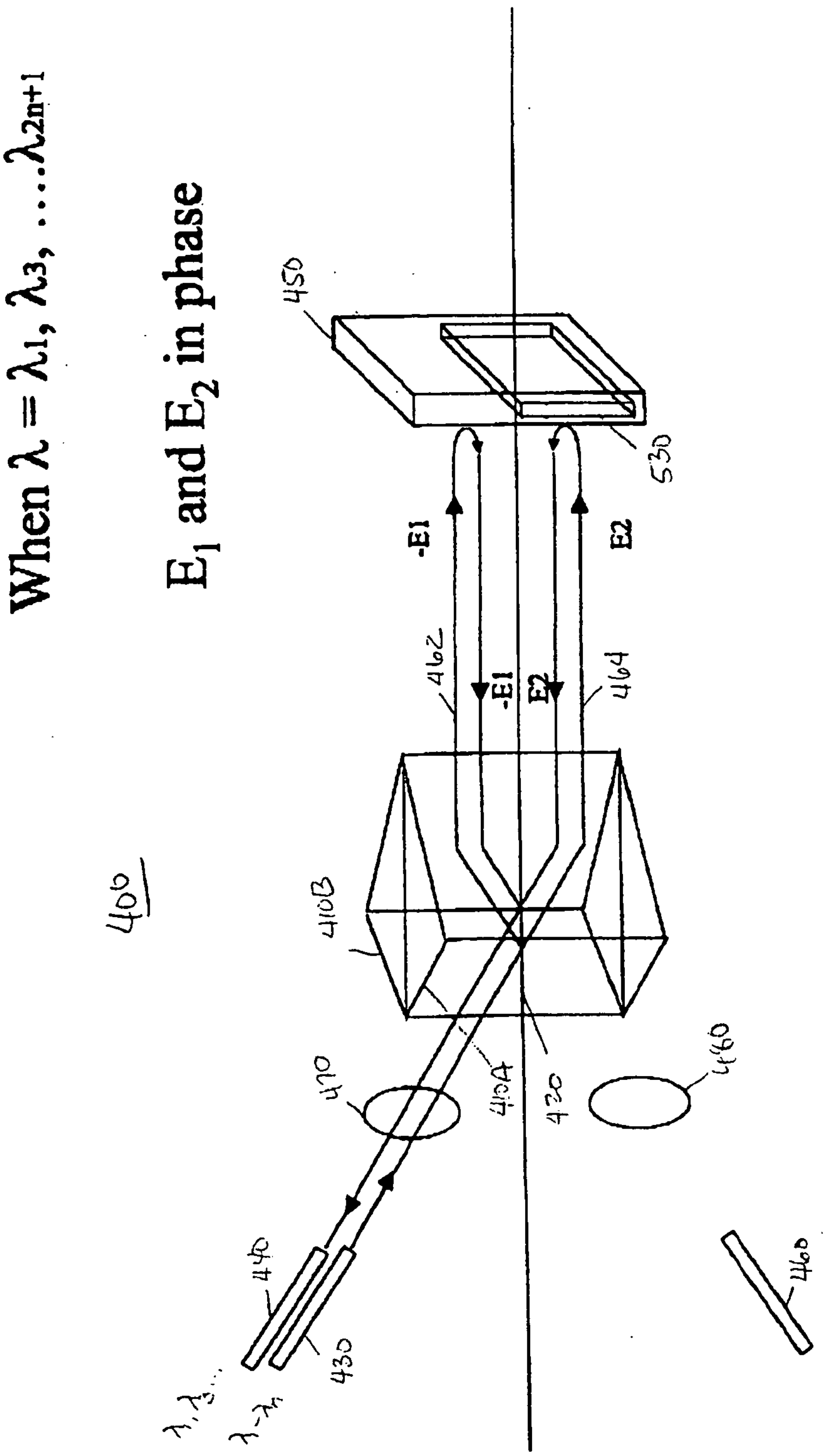
When $\lambda = \lambda_1, \lambda_3, \ldots.\lambda_{2n+1}$
E_1 and E_2 in phase
400
410B
410A
420
430
440
450
460
462
464
470
530
-E1
E2
$\lambda_1 \lambda_3 \ldots$
$\lambda_2 \lambda_n$

FIGURE 6

When $\lambda = \lambda_2, \lambda_4, \ldots.\lambda_{2n}$

E_1 and E_2 out of phase

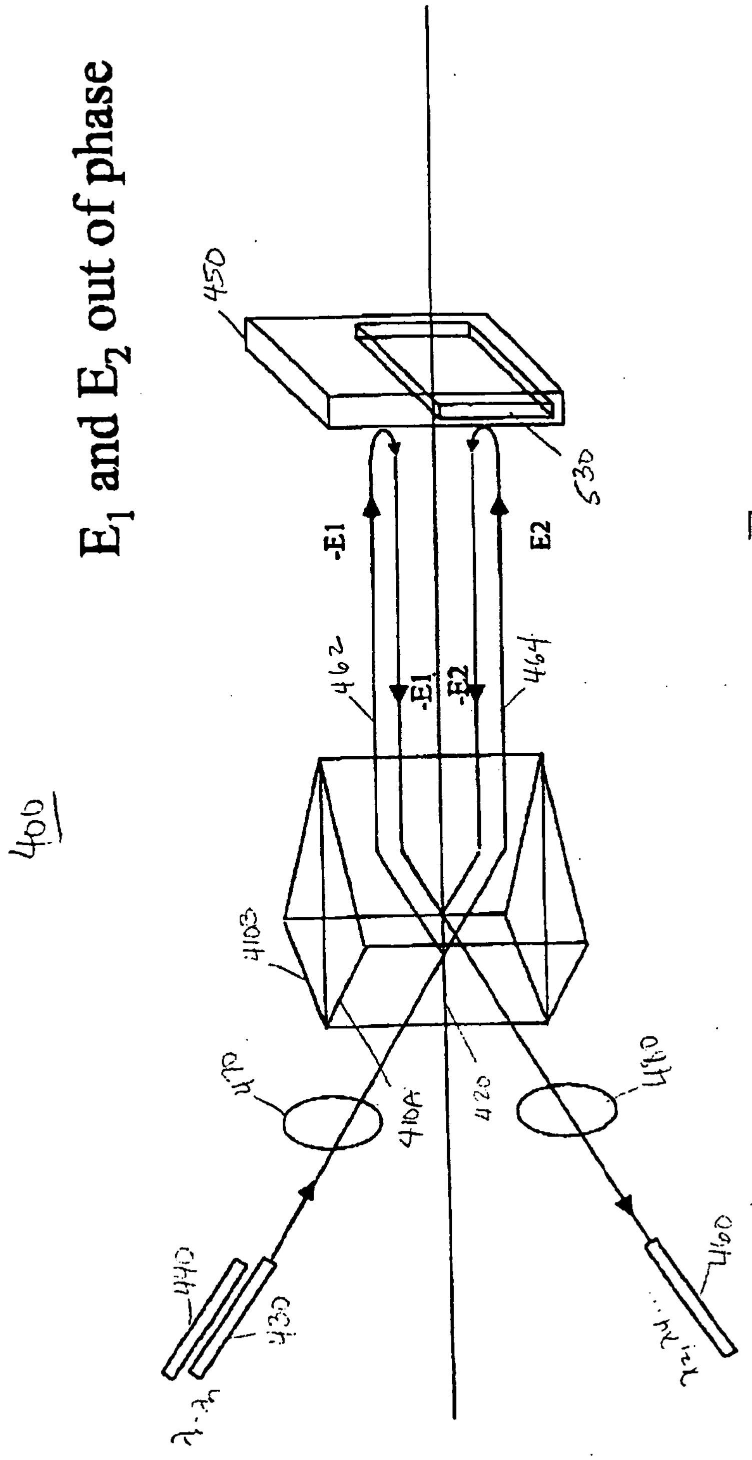

FIGURE 7

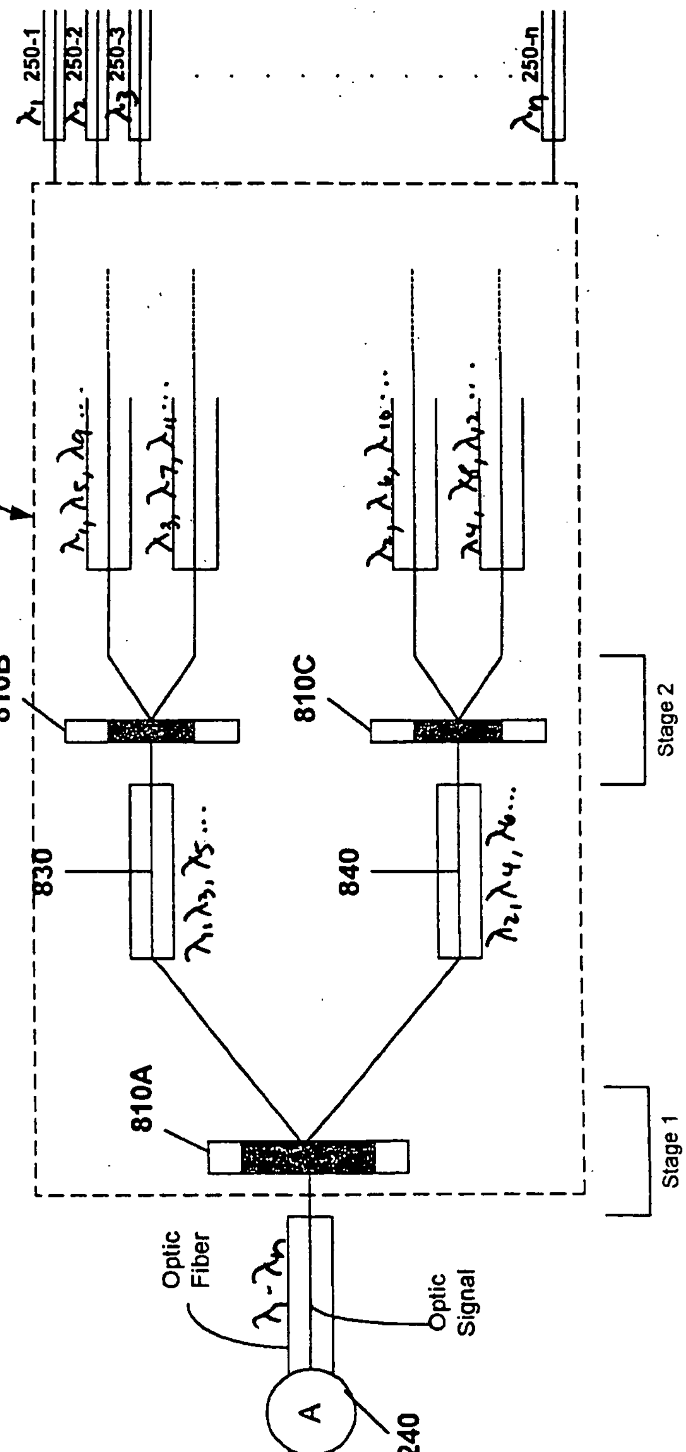
250-1
250-2
250-3
250-n
800
810A
810B
810C
830
840
Stage 1
Stage 2
Optic Fiber
Optic Signal
A
240

FIGURE 8

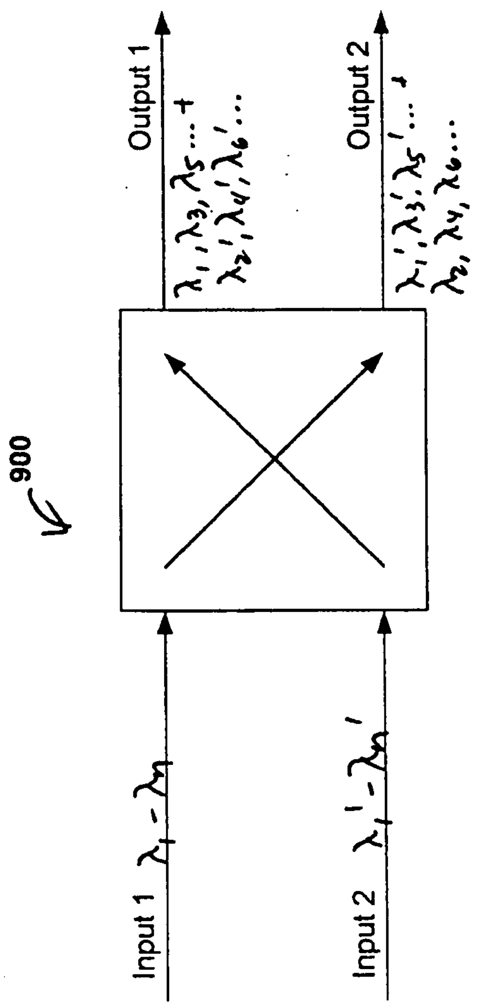
900
Input 1 $\lambda_1 - \lambda_n$
Input 2 $\lambda_1' - \lambda_n'$
Output 1
$\lambda_1, \lambda_3, \lambda_5 \ldots +$
$\lambda_2', \lambda_4', \lambda_6' \ldots$
Output 2
$\lambda_1', \lambda_3', \lambda_5' \ldots +$
$\lambda_2, \lambda_4, \lambda_6 \ldots$

FIGURE 9

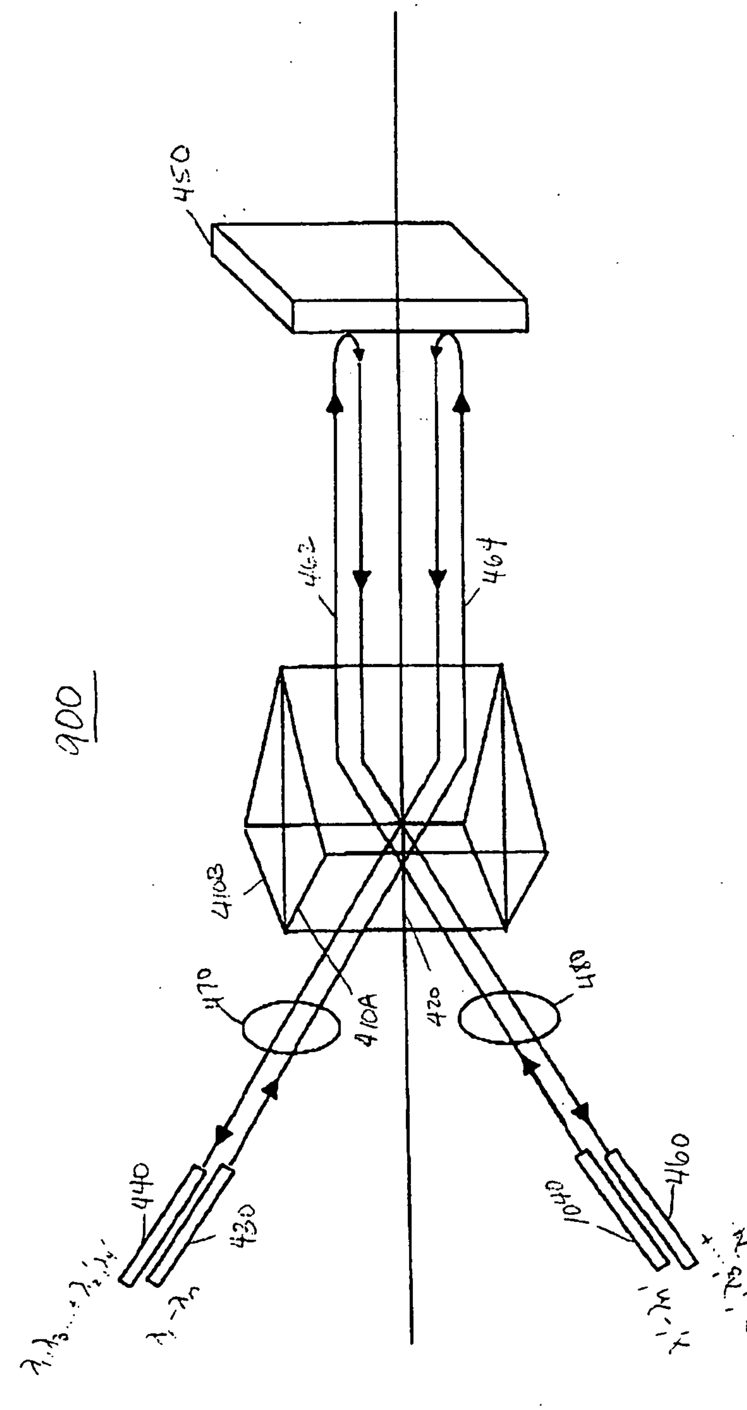

FIGURE 10